Project: **1337**
Project title: **Land Management, climate and financial markets**
Principal investigator: **Leonore Jungandreas**
Allocation period: **2023-01-01 to 2023-12-31**

Projekt overview

Managed agricultural land (including managed grasslands) covers about 40% (in 2018) of the total area in Europe. It is known to strongly influence the climate system via biogeochemical and biogeophysical feedbacks on local, regional and global scales. Via these feedbacks, more sustainable land management methods have the potential to beneficially impact the climate and regional weather conditions. However, to (further) evaluate these potentials, we first need a more comprehensive assessment of various land management methods in climate models, which allows us to explore climate mitigation and adaption strategies of such methods further.

Land management will become increasingly important due to land scarcity, the need for more efficient usage, or its role in carbon dioxide removal. Several studies have started investigating the evolving biogeophysical land-atmosphere feedbacks due to different land management methods. These studies focused mainly on irrigation (e.g., Lobell et al., 2006; Douglas et al., 2008; Hirsch et al., 2017; Thiery et al., 2017), forest management (e.g., Nabel et al., 2020) and albedo/residue management (e.g., Davin et al., 2014; Hirsch et al., 2018). Other sustainable agriculturing methods, such as annual vs. perennial cropping, crop harvest vs. catch cropping, cover crops, intensive vs. extensive grassland management, fallow land or agroforestry systems, are not or only rarely investigated yet, especially with coupled climate models.
But before they are adapted in the field, we first need a better assessment of the local and non-local effects of different land management methods to reduce the uncertainties in the involved biogeophysical feedbacks.

With this project, we aim to contribute to the scientific knowledge of how land management, specifically cover crops and agroforestry, interacts with weather extremes and local and regional climate. Can they serve as mitigation or adaption strategies?

This project is part of the Breathing Nature Excellence cluster initative from the University of Leipzig in collaboration with the German Center for Integrative biodiversity Research (iDiv; part of University Leipzig), the Halle Institute for Economic research, the Helmholtz Center for Environmental Research (UFZ), the Leibnitz Institute for Tropospheric Research, the Max Planck Institute for Biogechemistry in Jena, the Friedrich Schiller University Jena and the Max Planck Institute for Evolutionary Anthropology.

Range of planned work from the scientific view

To investigate how land management interacts with the climate system (Task 1), we will perform sensitivity experiments imitating cover crops (Task 1.A) and a first idealized representation of agroforestry (Task 1.B). For this purpose, we will use the coupled atmosphere-land model ICON/JSBACH4 developed by the MPI-M.
The focus of our work will be analyzing the evolving land-atmosphere interactions, focusing on the biogeophysical feedbacks. We will assess these feedbacks by comparing

the simulations with modified land management (i.e. cover crops or agroforestry) to the default ICON/JSBACH setup.

Previously mentioned studies, which modeled interactions of land management with the atmosphere, simulated on relatively coarse horizontal resolutions (~40-200km), losing many of the heterogeneous land surface characteristics. The model framework of ICON/JSBACH4 in its SAPPHIRE setup allows for nesting strategies down to storm-resolving scales.
Using such a nesting setup enables us to perform simulations with a much finer horizontal resolution of up to 2.5km. On the one hand, these storm-resolving simulations allow for a more detailed description of the heterogeneous characteristics of the land surface. On the other hand, convective processes can be explicitly resolved. The latter is essential for representing several precipitation characteristics (such as intensity and frequency) (e.g., Randall et al, (2003), Hohenegger et al. (2009), Stevens et al. (2019)). We argue, simulating with explicitly resolved convection is essential for representing increasing extreme events and their impacts on the land surface (e.g., on runoff, erosion, soil moisture). Hence, here we propose an advanced methodology to study land management-climate interactions using high-resolution simulations.

We plan to simulate
1) 5 ensembles of 30 years (inkl. spinup) at 20km horizontal resolution.
2. We will perform one year of nested simulations, including simulations with 20km, 10km, 5km, and 2.5km horizontal resolution.
The simulation domain for all simulations will cover Europe.

In the second step, we aim to include human decisions/behavior into the feedback loop to increase the benefits of the investigations mentioned above. The goal is to provide insights into whether and how financial markets (e.g., agricultural insurance) can be valuable tools to promote the implementation of such sustainable land management methods. However, for this Task 2, we will apply for computation time in the next period.

Mathematical and/or computational aspects

Our study will use the ICON/JSBACH model framework in the ICON-Sapphire setup. The simulations will cover the domain of Europe with up to 2.5km horizontal grid spacing and 90 vertical levels.

Algorithmic/mathematical/numerical methods and solution procedures

We will use the ICON-Sapphire model setup to perform the high-resolution simulations. It allows for explicitly resolving many atmospheric processes instead of parameterizing them (Hohenegger et al. (under review)).

Particular suitability to solve the problem with the help of HLRE-4

The ICON/JSBACH model framework has been developed by the MPI-M and the DWD. Therefore, it is well adapted for the HLRE-4 architecture of Levante. Several simulations were already performed using the ICON-Sapphire model framework on Levante. Especially the high-resolution simulations require substantial computational power and resources, which make it necessary to use an HPC system as HLRE-4.

Performance benefits depending on the number of used CPUs (scalability)

The ICON/JSBACH model framework is parallelized and optimized to run on the HLRE-4 system.

Required computing time and amount of storage space

All numbers in the Table below are estimated values based on Tabel 1 of Hohenegger et al. (under review). More specifically I calculated all numbers based on their global 2.5km-simulation (20 SDPD on 600 nodes for 83.886.080 cells).
An example calculation I did:
- Europe domain with 2.5km horizontal resolution and 90 vertical levels: 2.814.752 cells
- 83.886.080 cells/ 14400 node hours = 2.814.752 cells / 484 node hours (for 20days)
- this gives ~8815 node hours for 1 year simulation

Task	Planned simulations		Simulation years	Node hours (Levante CPU)	Archive project (TiB)	Levante Storage (TiB)	Archive long term (TiB)
1) Sensitivity experiments of sustainable land management with ICON-Sapphire	Spinup and natural variability: **default setup**	30 years x 5 ensembles	150	75.0	2.0	10.0	2.0
	Spinup and natural variability: **cover crops setup**	30 years x 5 ensembles	150	75.0	2.0	10.0	2.0
	Spinup and natural variability: **agroforestry setup**	30 years x 5 ensembles	150	75.0	2.0	10.0	2.0
	Nesting simulations up to storm resolving scales: **default setup**	20km-domain	1	0.5	0.01	1	0.01
		10km-domain	1	14	0.0	2	0.0
		5km-domain	1	371	1.0	10	1.0
		2.5km-domain	1	8815	4.0	14	4.0
	Nesting simulations up to storm resolving scales: **cover crops setup**	20km-domain	1	0.5	0.01	1	0.01
		10km-domain	1	14	0.0	2	0.0
		5km-domain	1	371	1.0	10	1.0
		2.5km-domain	1	8815	4.0	14	4.0
	Nesting simulations	20km-domain	1	0.5	0.01	1	0.01

	up to storm resolving scales: **agroforestry setup**	10km-domain	1	14	0.0	2	0.0
		5km-domain	1	371	1.0	10	1.0
		2.5km-domain	1	8815	4.0	14	4.0
Total				**27827**	**21**	**114**	**21**

In the following, we describe the planned simulations in more detail:
1) the 30-year simulations will be performed for two purposes: First, these simulations serve as spinup for soil moisture. The respective nested simulations will be started from a restart file of these simulations after the soil moisture is equilibrated. Second, by performing five ensembles of these "spinup" simulations, we can estimate the climate system's natural variability under the simulated conditions. Considering natural variability in our analysis will improve the results and the study's reliability.
All spinup simulations will be performed at 20km horizontal grid spacing. We will simulate over Europe with domain boundaries reaching from 25°W-55°E and 26°N-76°N. In total, three 30-year simulations (each with 5 ensembles) will be performed: one simulation with the default setup, one simulation imitating cover crops, and one simulation imitating agroforestry.

2) To perform the storm-resolving simulations we will use a nesting setup, starting with the 20km horizontal resolution domain as the parent domain and then reducing the grid spacing by a factor of 2 down to 10km, 5km, and 2.5km horizontal grid spacing. The latter two resolutions allow for the explicit treatment of convection. We aim to use 5km and 2.5km with explicit convection to test whether the increased heterogeneity of the land surface affects the results.
Similarly to the spinup simulations, three nested experiments will be performed: the default setup, imitating cover crops, and agroforestry covering Europe. Due to the nesting the the inner domains will be slightly smaller than the 20km domain.

Additional value compared to other projects

This project advances our understanding of land management-climate interactions and is complementary to projects of, for example, Julia Pongratz, which focuses on forest management-climate interactions. Therefore, it contributes to a more complete representation of the land surface in climate models.

References

Davin, E. L., Seneviratne, S. I., Ciais, P., Olioso, A., & Wang, T. (2014). Preferential cooling of hot extremes from cropland albedo management. *Proceedings of the National Academy of Sciences*, *111*(27), 9757-9761.

de Vrese, P., Hagemann, S., & Claussen, M. (2016). Asian irrigation, African rain: Remote impacts of irrigation. *Geophysical Research Letters*, *43*(8), 3737-3745.

Douglas, E. M., Beltrán-Przekurat, A., Niyogi, D., Pielke Sr, R. A., & Vörösmarty, C. J. (2009). The impact of agricultural intensification and irrigation on land–atmosphere interactions and Indian monsoon precipitation—A mesoscale modeling perspective. *Global and Planetary Change*, *67*(1-2), 117-128.

Hirsch, A. L., Wilhelm, M., Davin, E. L., Thiery, W., & Seneviratne, S. I. (2017). Can climate-effective land management reduce regional warming?. *Journal of Geophysical Research: Atmospheres*, *122*(4), 2269-2288.

Hirsch, A. L., Prestele, R., Davin, E. L., Seneviratne, S. I., Thiery, W., & Verburg, P. H. (2018). Modelled biophysical impacts of conservation agriculture on local climates. *Global change biology*, *24*(10), 4758-4774.

Hohenegger, C., Brockhaus, P., Bretherton, C. S., & Schär, C. (2009). The soil moisture–precipitation feedback in simulations with explicit and parameterized convection. *Journal of Climate*, *22*(19), 5003-5020.

Hohenegger, C., Korn, P., Linardakis, L., Redler, R., Schnur, R., Adamidis, P., ... & Stevens, B. (2022). ICON-Sapphire: simulating the components of the Earth System and their interactions at kilometer and subkilometer scales. *Geoscientific Model Development Discussions*, 1-42.

Lobell, D., Bala, G., Mirin, A., Phillips, T., Maxwell, R., & Rotman, D. (2009). Regional differences in the influence of irrigation on climate. *Journal of Climate*, *22*(8), 2248-2255.

Nabel, J. E., Naudts, K., & Pongratz, J. (2020). Accounting for forest age in the tile-based dynamic global vegetation model JSBACH4 (4.20 p7; git feature/forests)–a land surface model for the ICON-ESM. *Geoscientific Model Development*, *13*(1), 185-200.

Randall, D., Khairoutdinov, M., Arakawa, A., & Grabowski, W. (2003). Breaking the cloud parameterization deadlock. *Bulletin of the American Meteorological Society*, *84*(11), 1547-1564.

Stevens, B., Satoh, M., Auger, L., Biercamp, J., Bretherton, C. S., Chen, X., ... & Zhou, L. (2019). DYAMOND: the DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains. *Progress in Earth and Planetary Science*, *6*(1), 1-17.

Thiery, W., Davin, E. L., Lawrence, D. M., Hirsch, A. L., Hauser, M., & Seneviratne, S. I. (2017). Present-day irrigation mitigates heat extremes. *Journal of Geophysical Research: Atmospheres*, *122*(3), 1403-1422.